

# Theory Lessons from the First LHC Runs at $O(1 \text{ TeV})$

Peter Skands (CERN PH-TH)

# Disclaimer

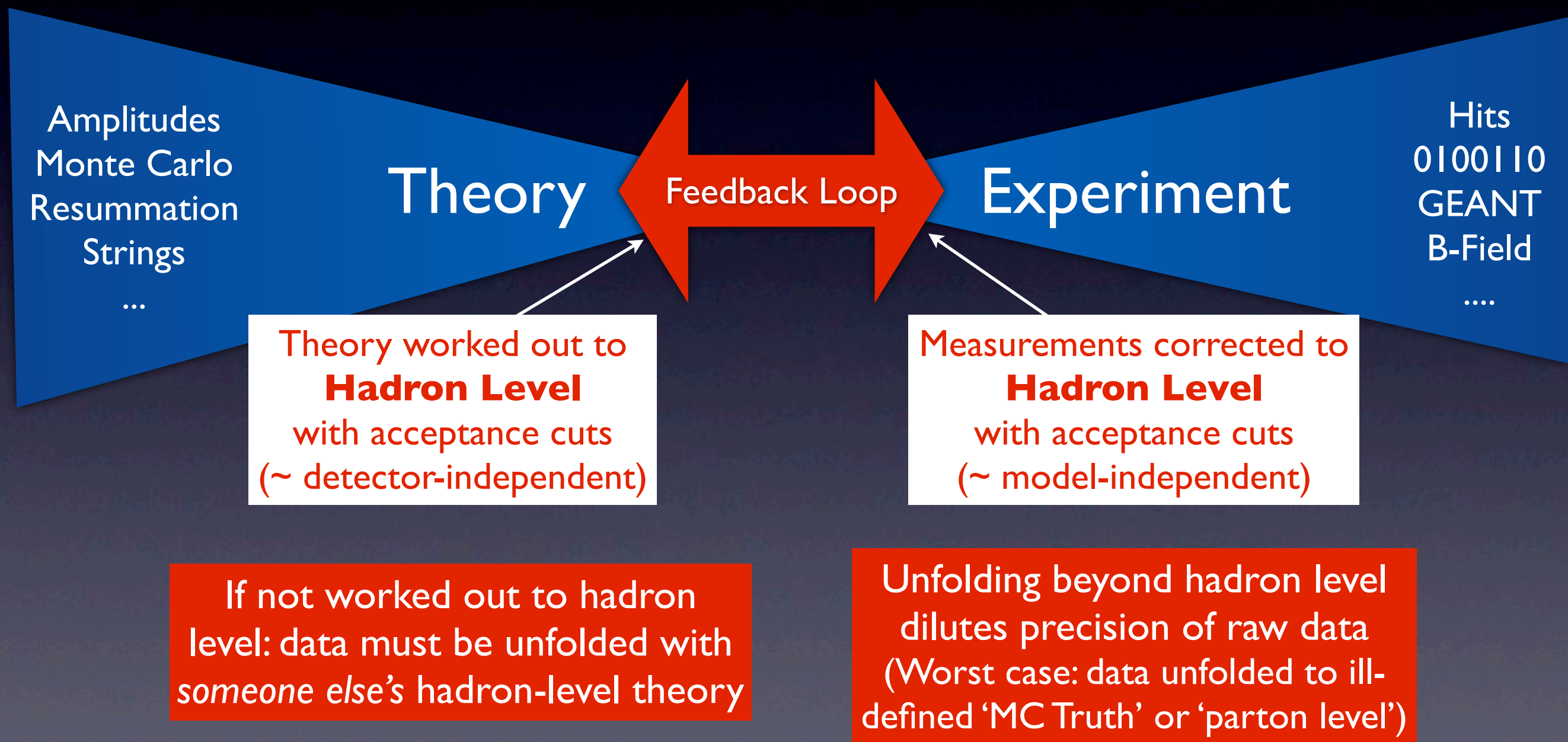
- Impossible to cover everything
- *Focus* on important outstanding questions which could be settled by early LHC measurements at 900 and 2360 GeV
- Note that, for most of them, this is our *only* chance to settle these questions
- The answers are crucial to improving our physics models

# Monte Carlos and Precision

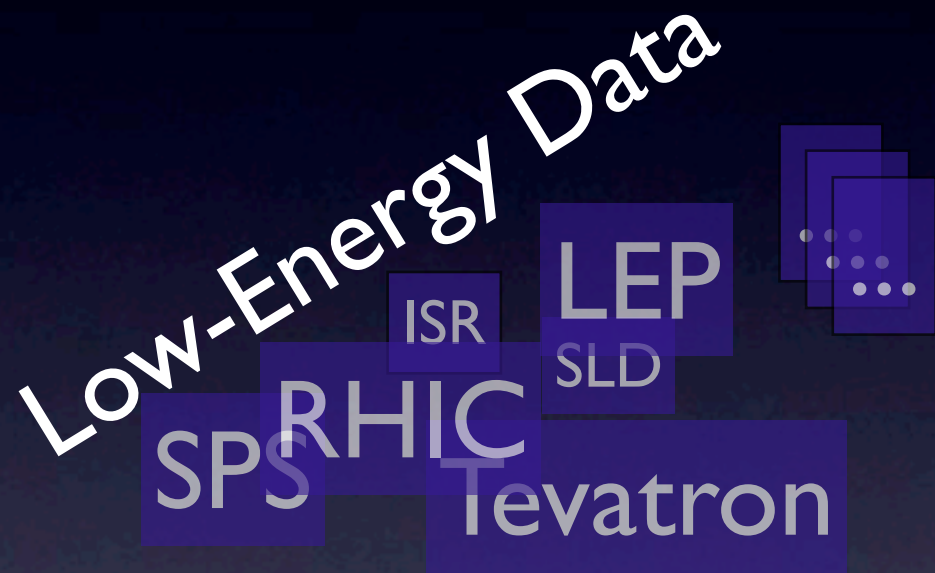
- A Good Physics Model gives you
  - Reliable calibrations for both signal and background (e.g., jet energy scales)
  - Reliable corrections (e.g., track finding efficiencies)
  - Background estimates with as small uncertainty as possible (fct of both theoretical accuracy and available experimental constraints)
  - Reliable discriminators with maximal sensitivity to New Physics



Count what is Countable  
**Measure what is Measurable**  
*(and keep working on the beam)* G. Galilei

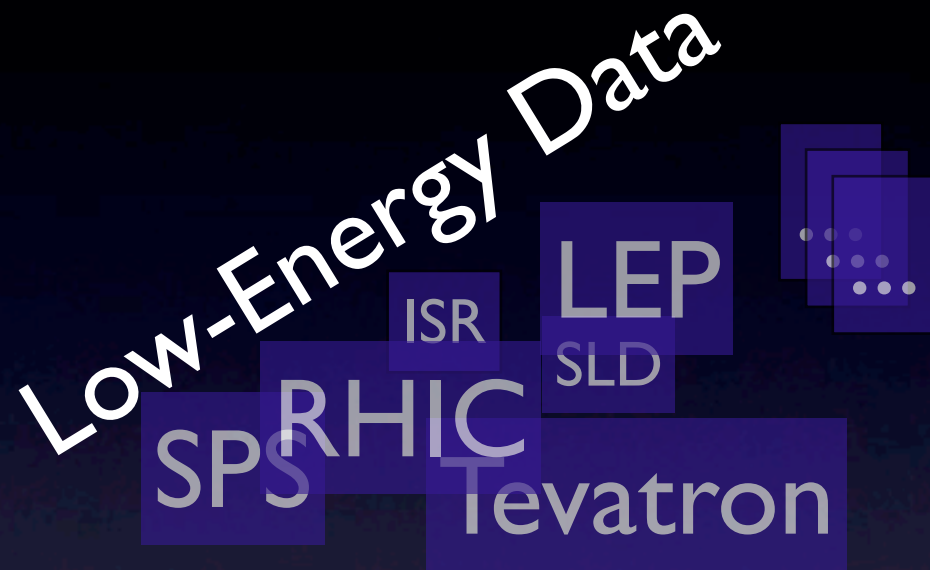


# Constraining Models



- A wealth of data available at lower energies
- Used for constraining ('tuning') theoretical models (E.g., Monte Carlo Event Generators)

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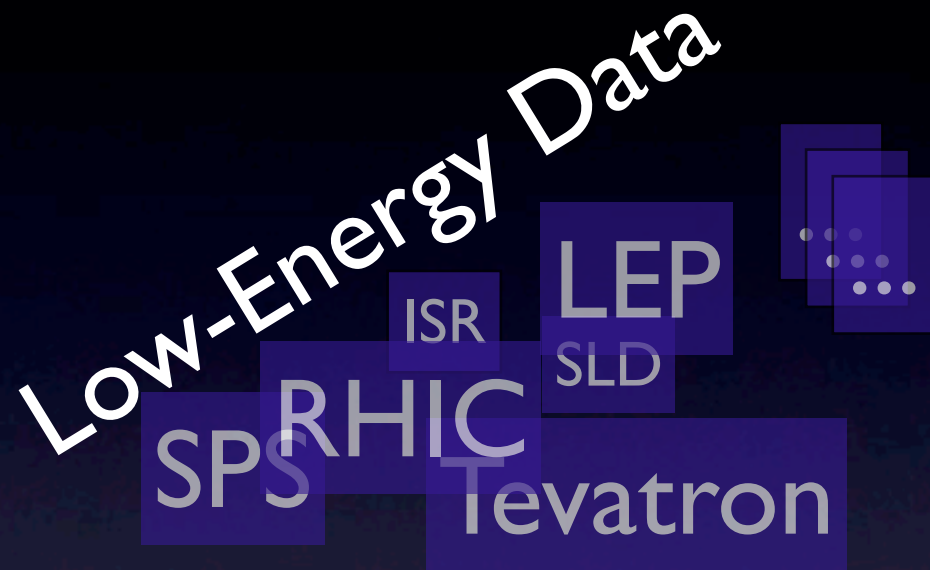


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- The low-energy LHC runs give us a *unique chance* to fill in gaps in our knowledge at lower energies
- Which model would you trust more? One that also describes SPS, RHIC, Tevatron, Low-Energy LHC? Or one that doesn't?



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**But wait ... which gaps?**

# Charged Multiplicity

- One of the most fundamental quantities to measure
  - But fundamental does not imply easy



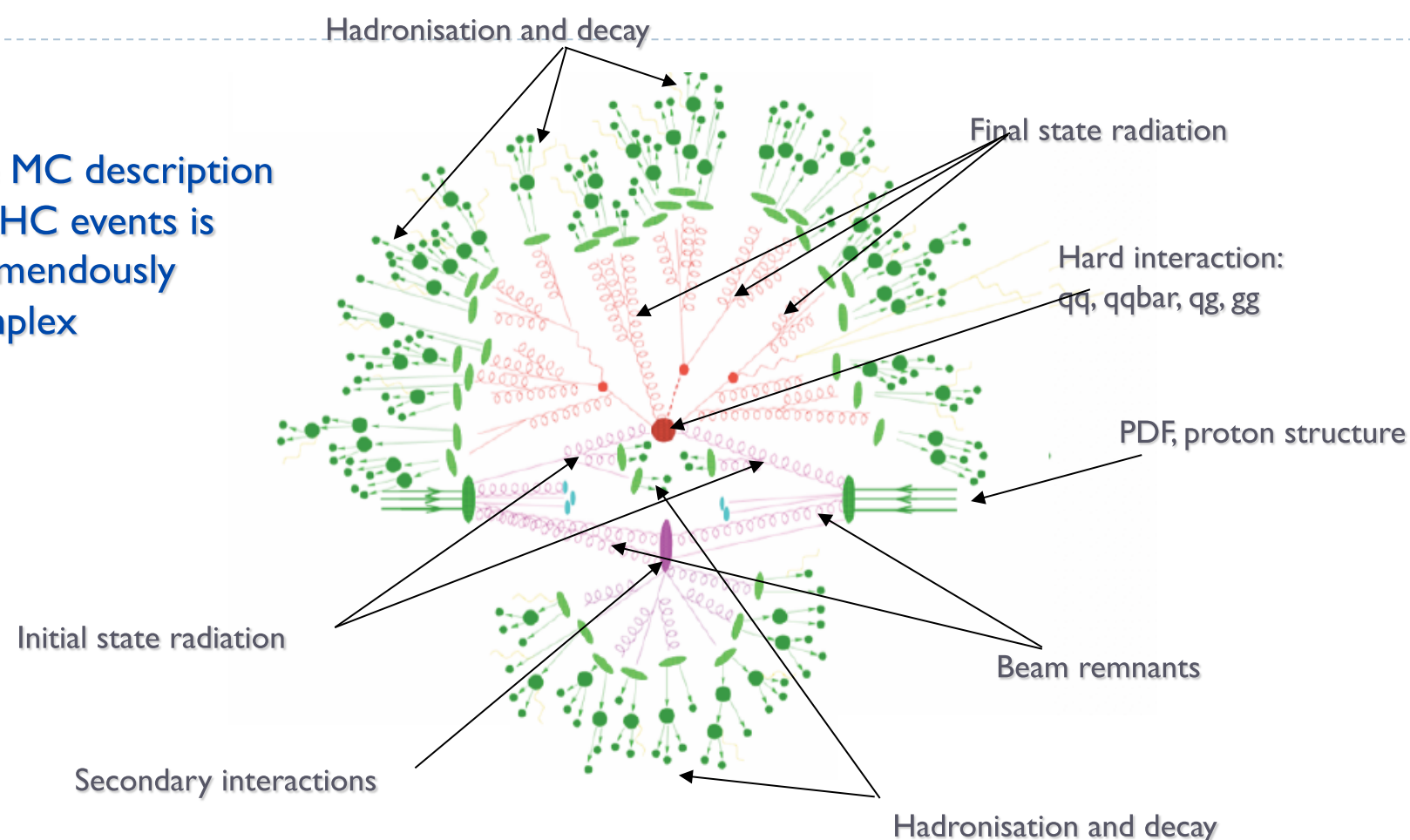
# Charged Multiplicity

- One of the most fundamental quantities to measure
  - But fundamental does not imply easy
  - Complications: Corrections for Trigger Bias, Diffraction, Zero Bin, Long-Lived particles, Extrapolations from raw measurement to: hadron-level (with acceptance cuts) and/or to: hadron-level (full phase space), ...

# Dissecting Minimum-Bias

## Physics requirements: basics

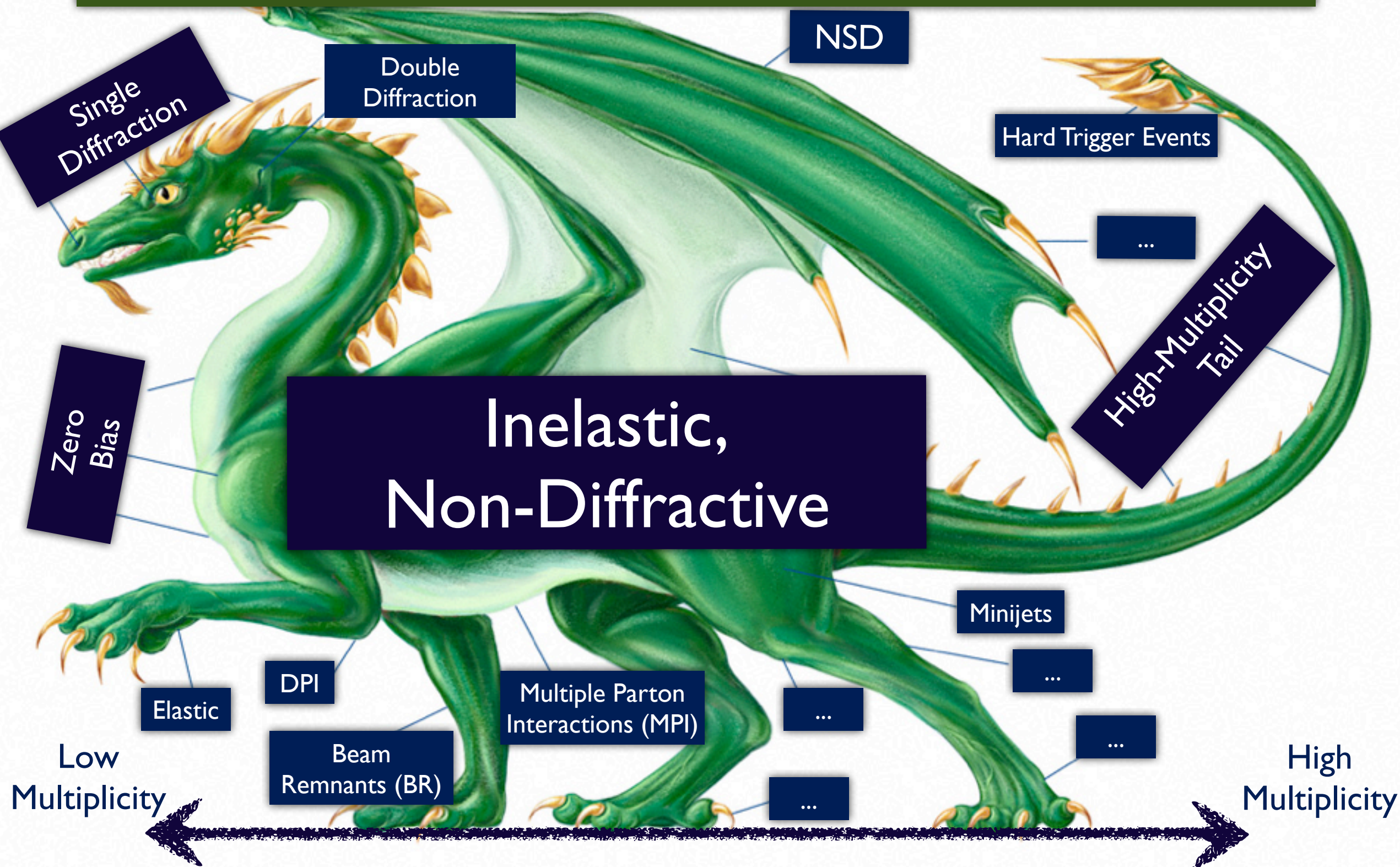
The MC description of LHC events is tremendously complex



This is a schematization to be able to cut down the problem in pieces and model them in a different way. The “pieces” are correlated !



# Dissecting Minimum-Bias





# Measured Results

- How to Compare to Older Measurements?
  - Bubble chambers etc extrapolated to full phase space
  - More model-dependent at Tevatron and LHC experiments

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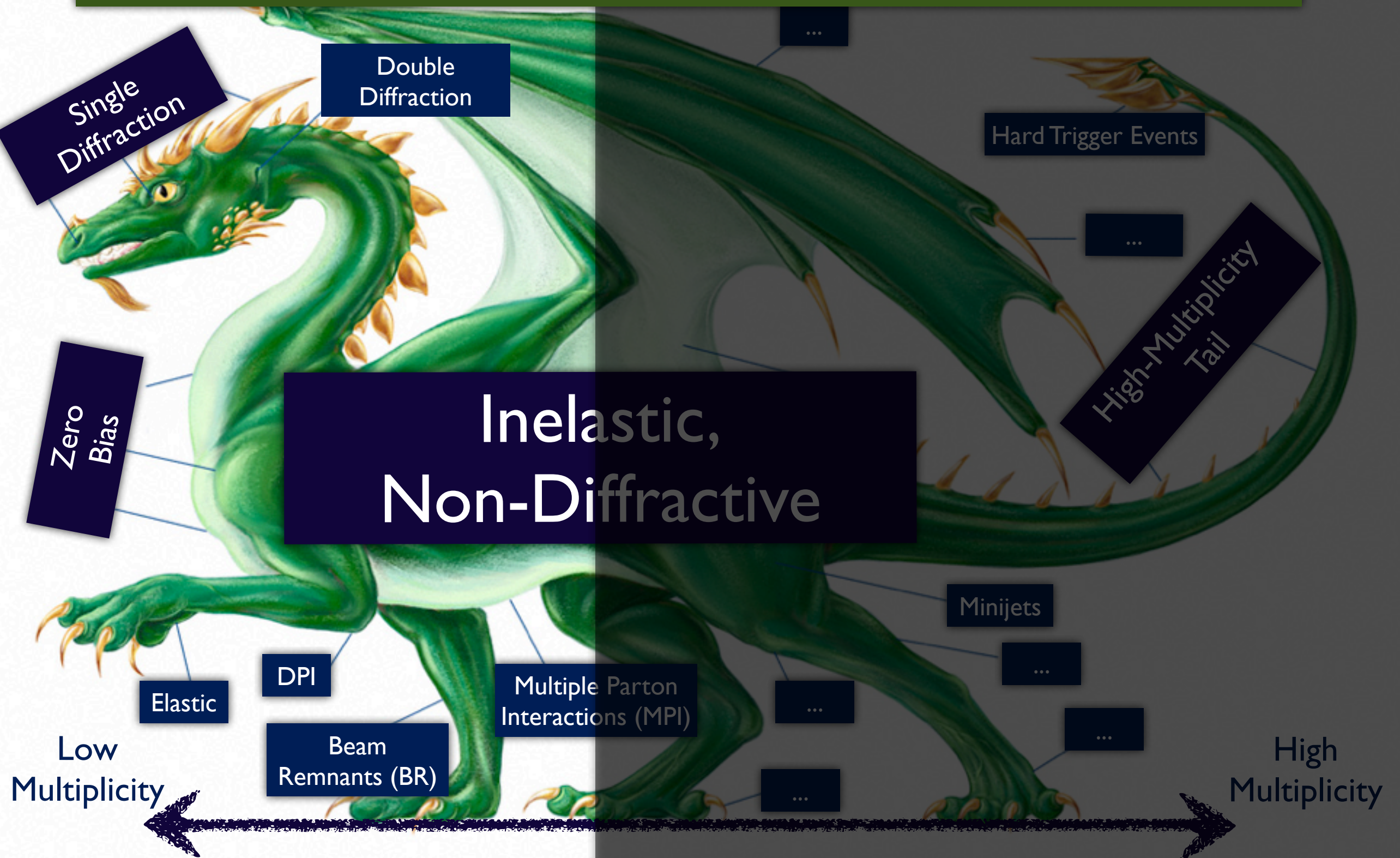
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- How to Compare to Theory?

- Inelastic > 'NSD' > Inelastic Non-Diffractive, ... ?
- For all: Define event set in terms of hadron-level cuts
- Today's theorists not interested in filling up unmeasured region with some model (especially if it is some other guy's model) - Keep main measured result as close to raw acceptance as possible. Extrapolate *only* to do comparisons (inflates uncertainties)



# Issues at Low Multiplicity



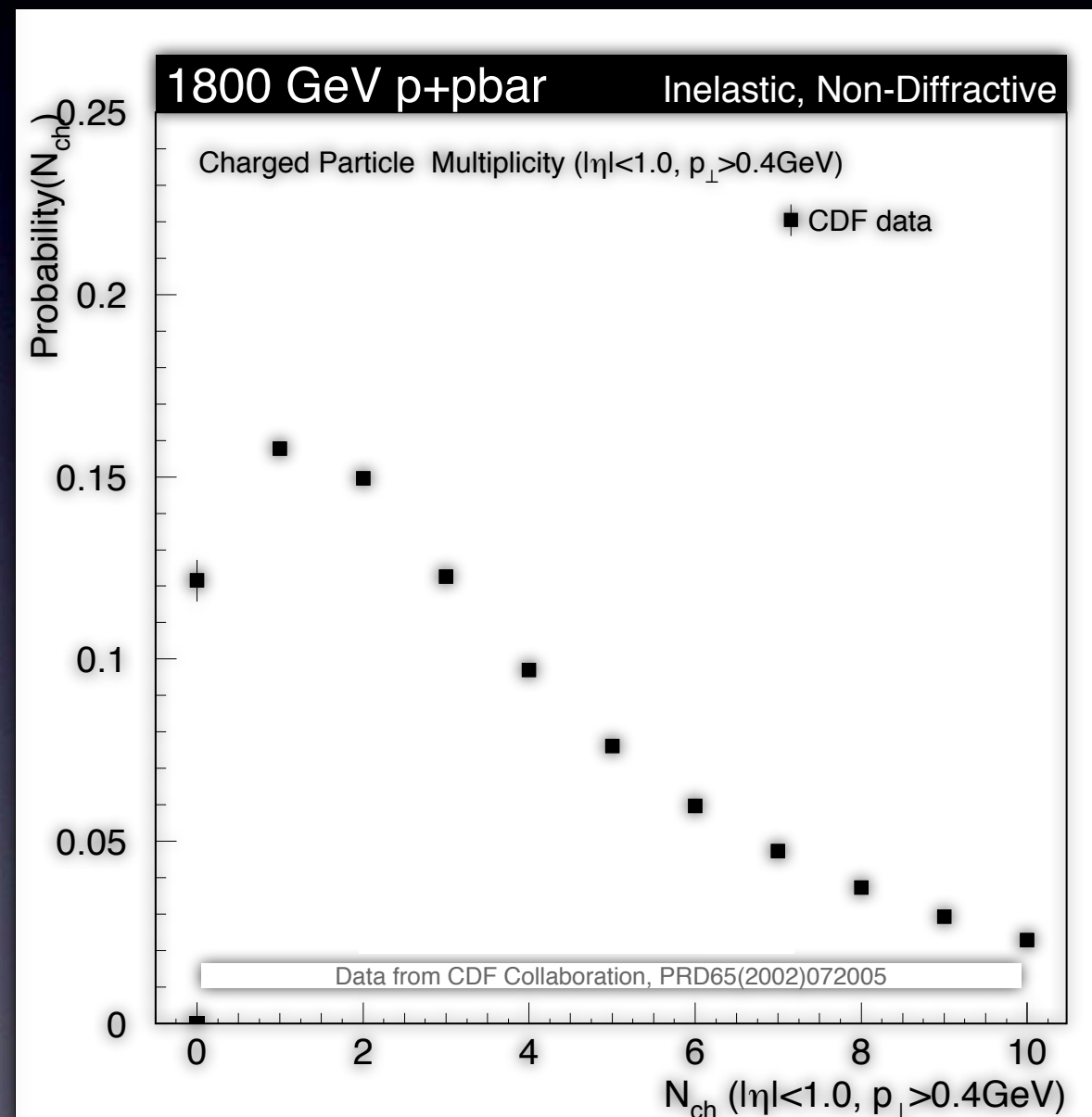


# Low Multiplicities: Correcting for Diffraction

- Diffractive processes
  - Large part of total cross section
  - Populate the low-multiplicity bins: lower  $\langle N_{ch} \rangle$
  - Characteristic rapidity spectrum with large rapidity gaps: affect  $dN_{ch}/d\eta$
  - Impossible to interpret min-bias spectra without knowing precisely how diffraction was treated

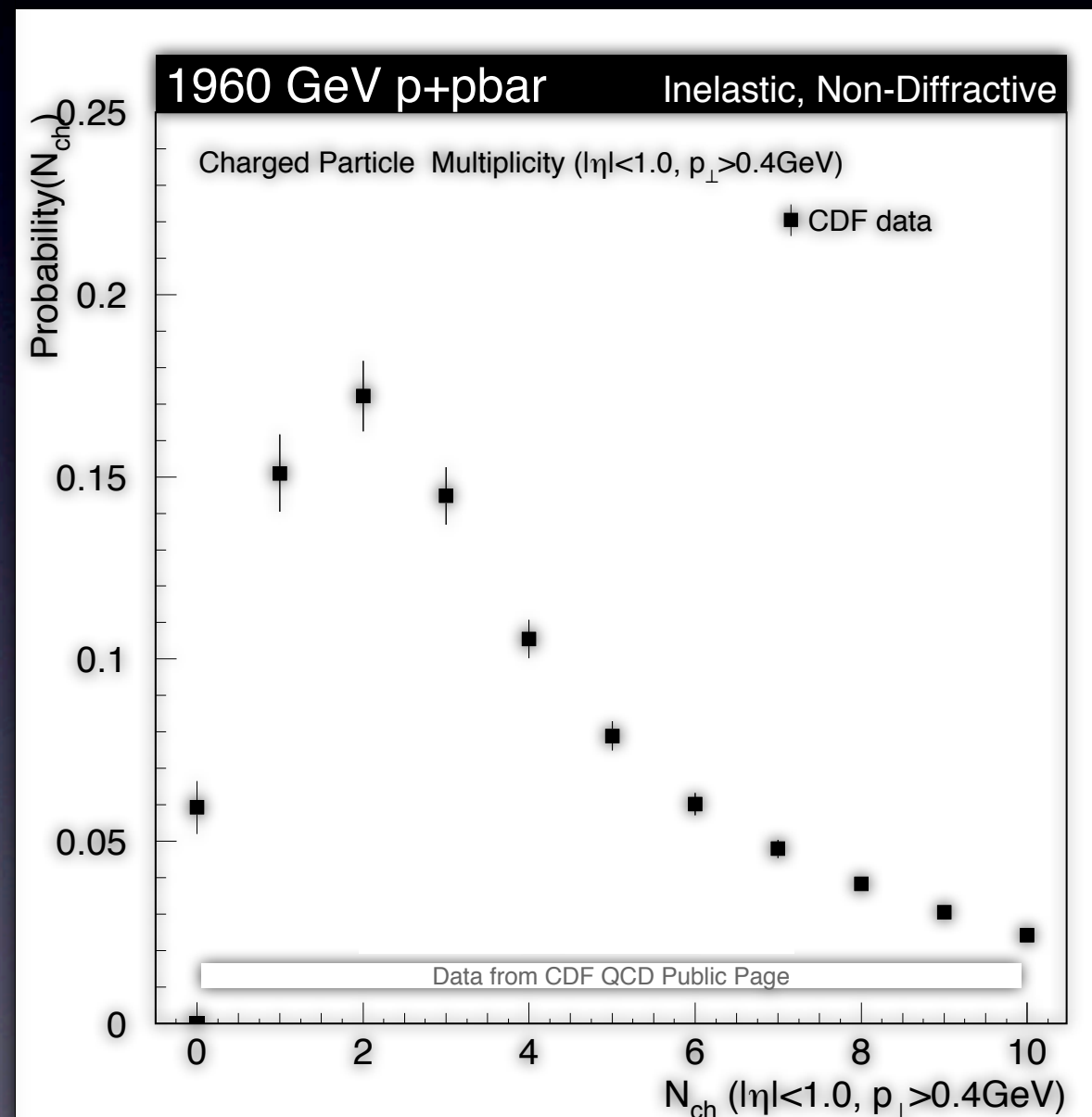
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- CDF Run-I Data
  - Corrected to  $p_T > 0.4$  GeV instead of full PS: less model dependence
  - First few bins corrected for diffraction (also affects average  $N_{ch}$  and  $dN/d\eta$ )



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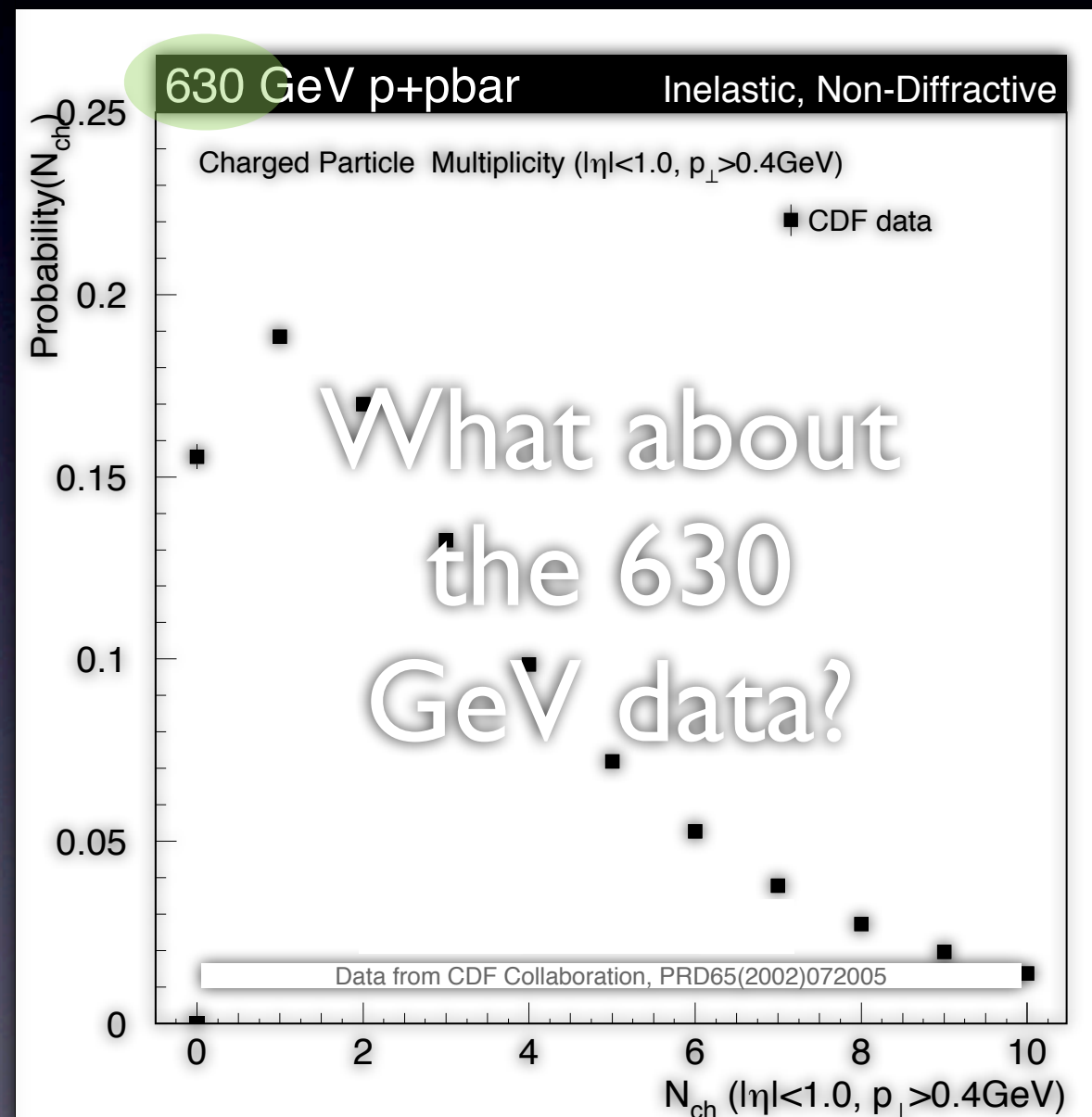
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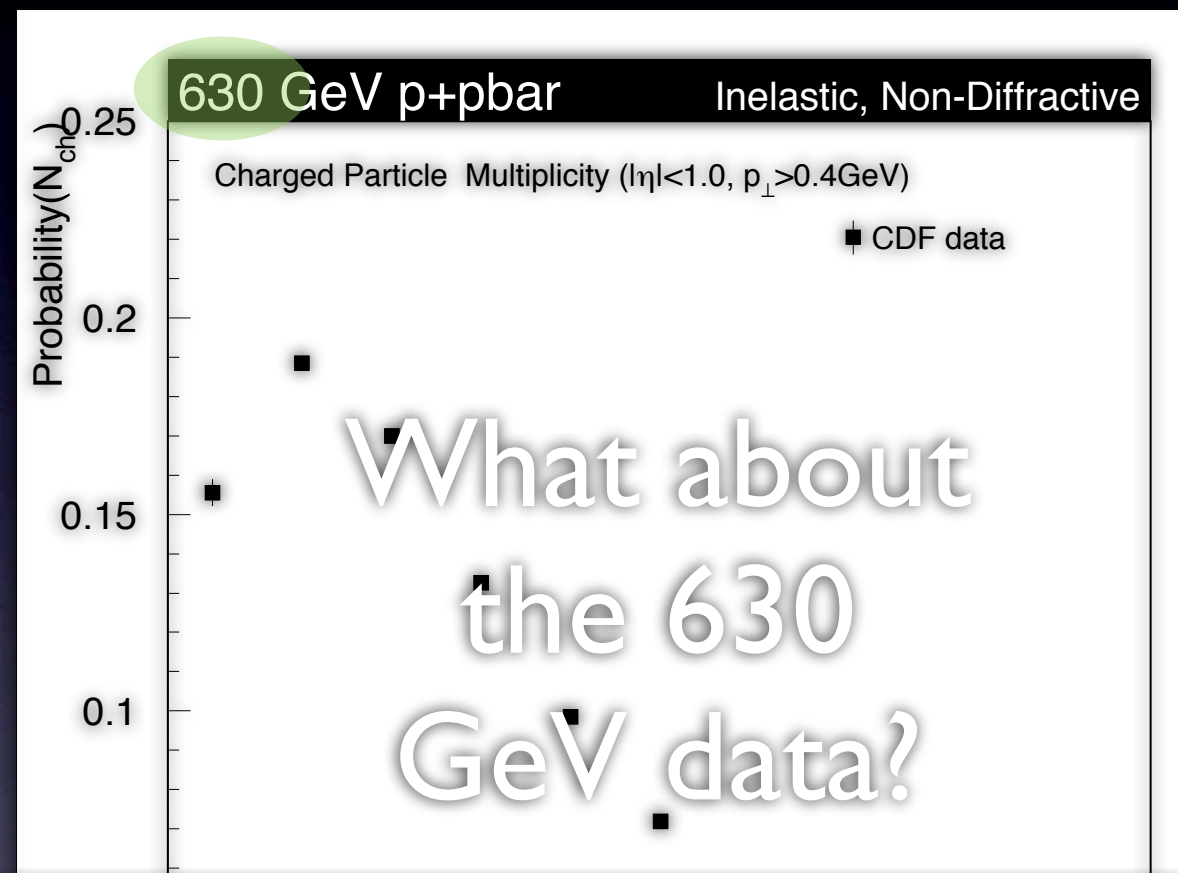
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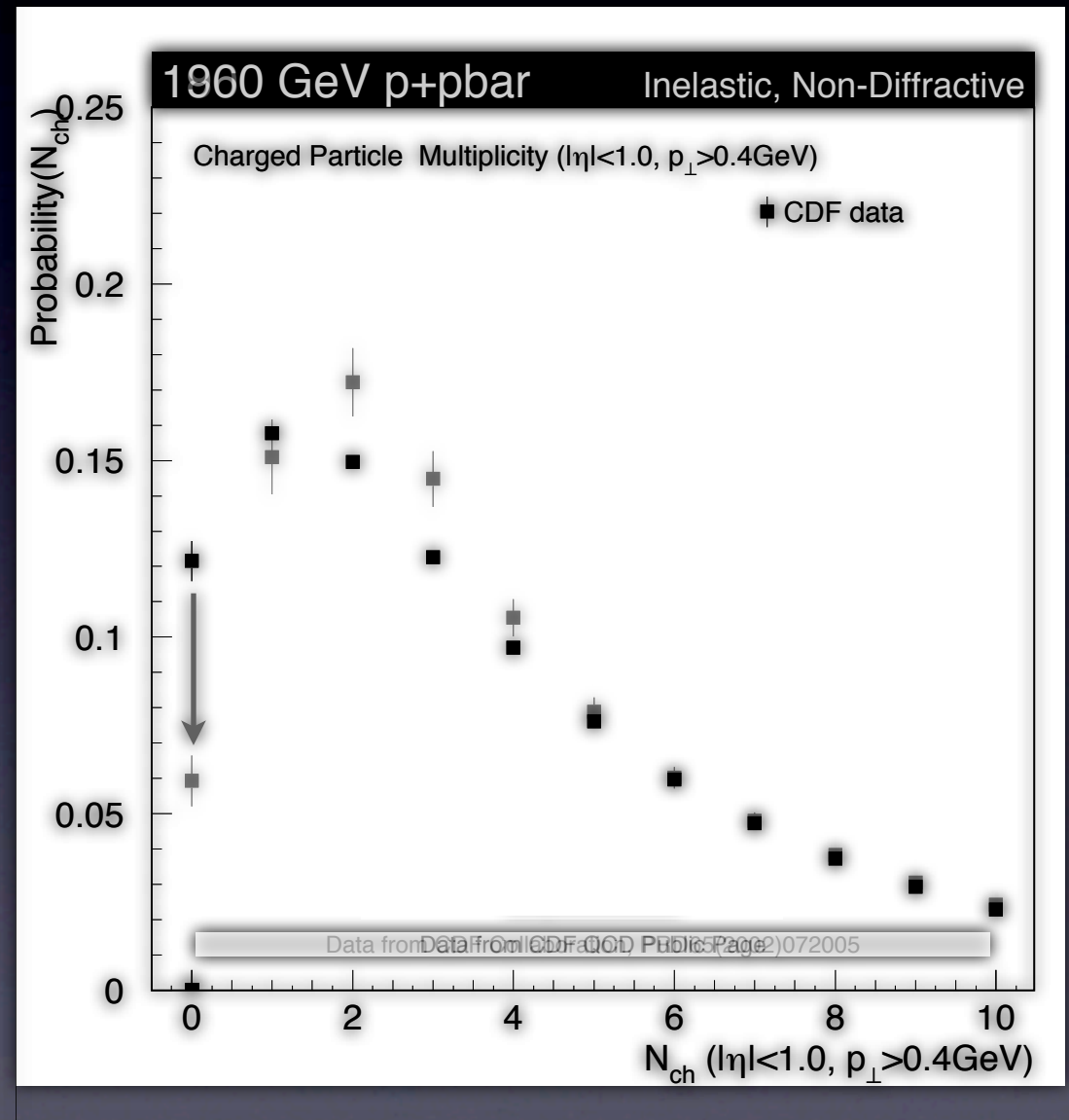
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LHC Measurements at 900 and 2360 GeV, with a well-defined, agreed-upon, definition of diffraction can kill this issue

# The Zero Bin

- The most problematic is the **zero bin**: *the event was triggered, but no fiducial tracks*
- *E.g, was it a diffractive event with no tracks, or an inelastic non-diffractive event, with no tracks? Or ... ?*





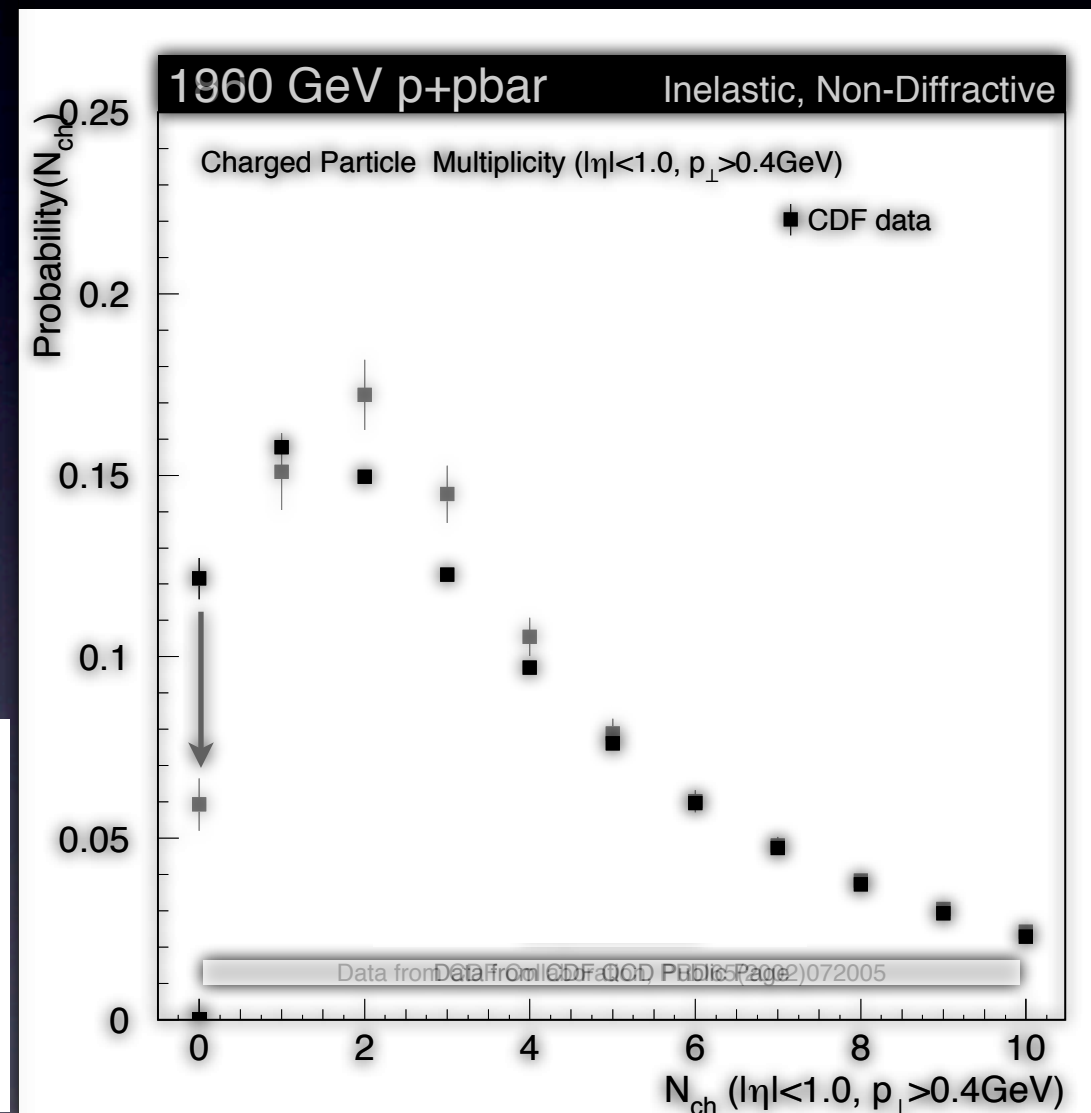
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Predictions for Mean Densities of Charged Tracks

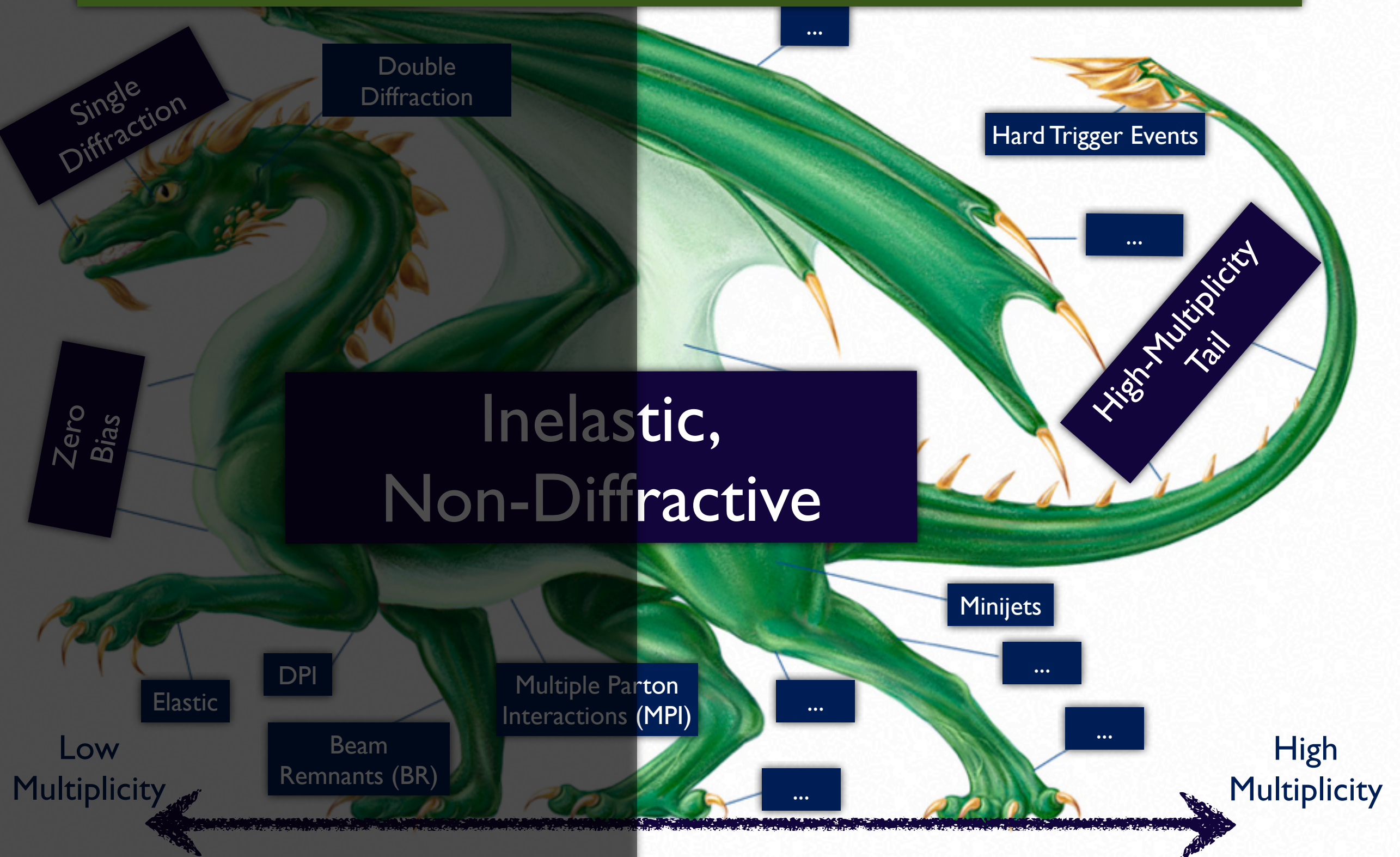
	$\frac{\langle N_{ch} \rangle  _{N_{ch} \geq 0}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle  _{N_{ch} \geq 1}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle  _{N_{ch} \geq 2}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle  _{N_{ch} \geq 3}}{\Delta\eta\Delta\phi}$
LHC 10 TeV	$0.40 \pm 0.05$	$0.41 \pm 0.05$	$0.43 \pm 0.05$	$0.46 \pm 0.06$
LHC 14 TeV	$0.44 \pm 0.05$	$0.45 \pm 0.06$	$0.47 \pm 0.06$	$0.51 \pm 0.06$

PS, Perugia Proceedings, arXiv:0905.3418 [hep-ph]



Redefine the event sample to include at least one fiducial track?

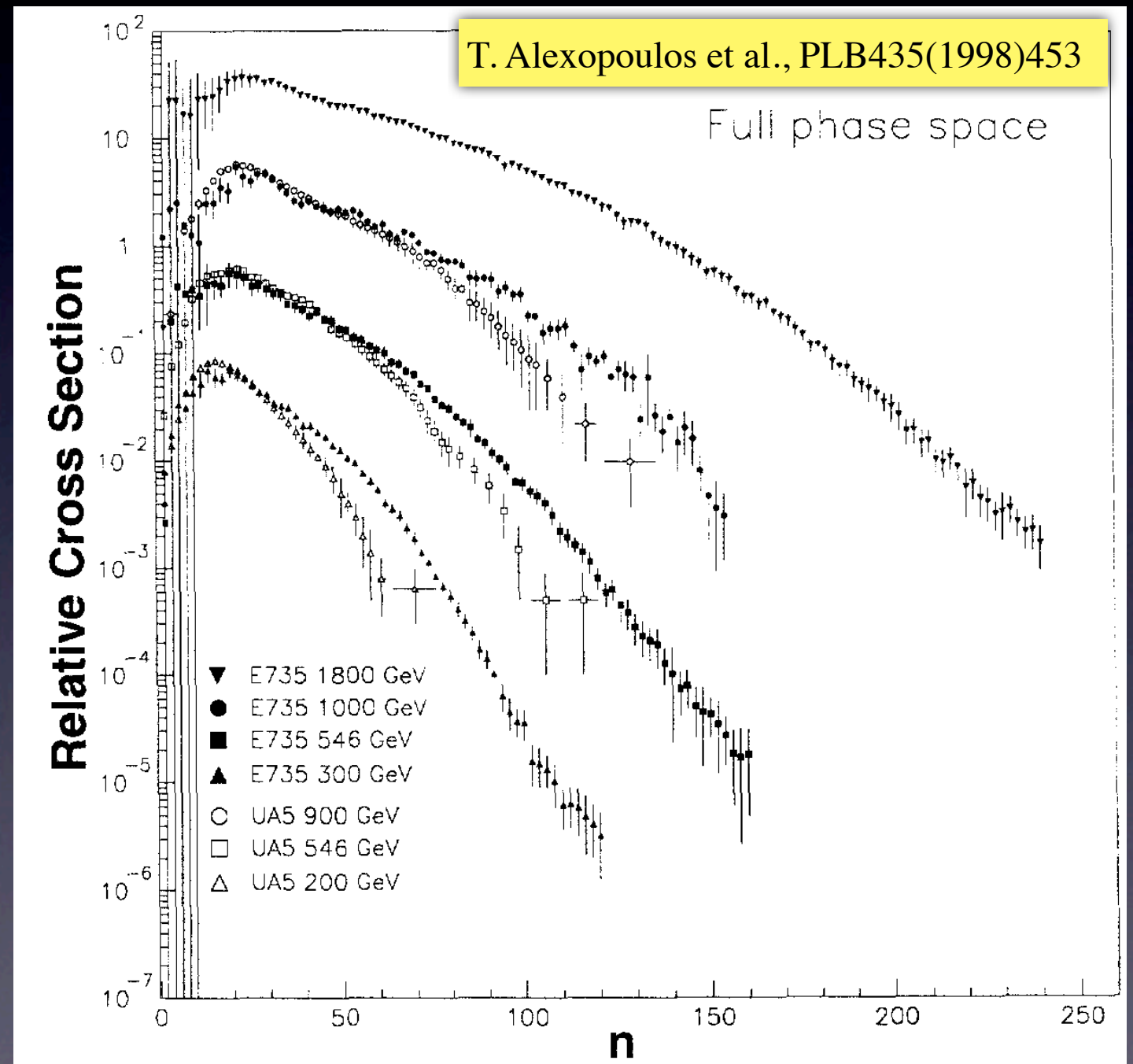
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# High Multiplicities: An Unresolved Question

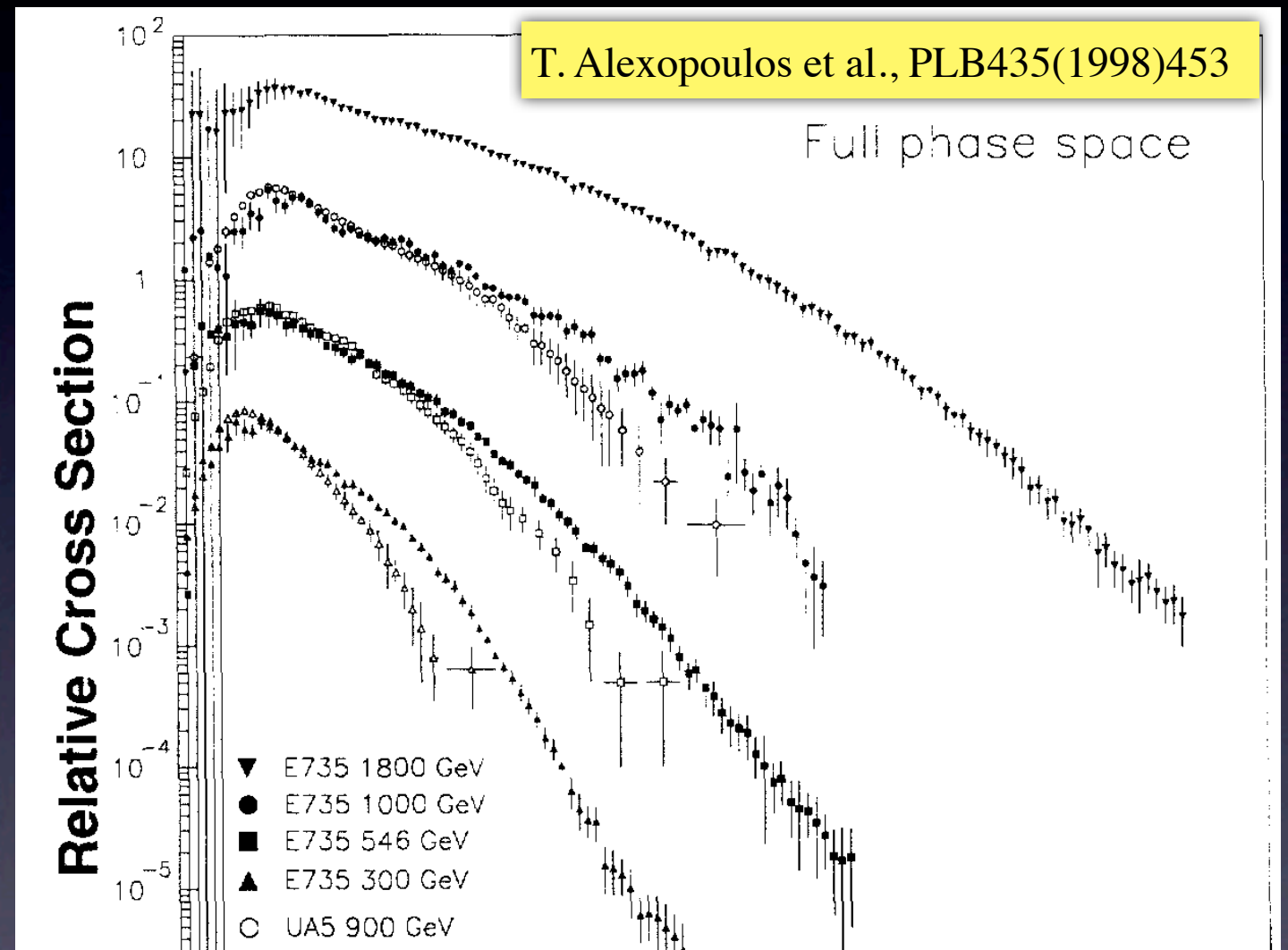
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- E735 at 300, 546, 1000, and 1800 GeV
- Mutually  
*Inconsistent over  
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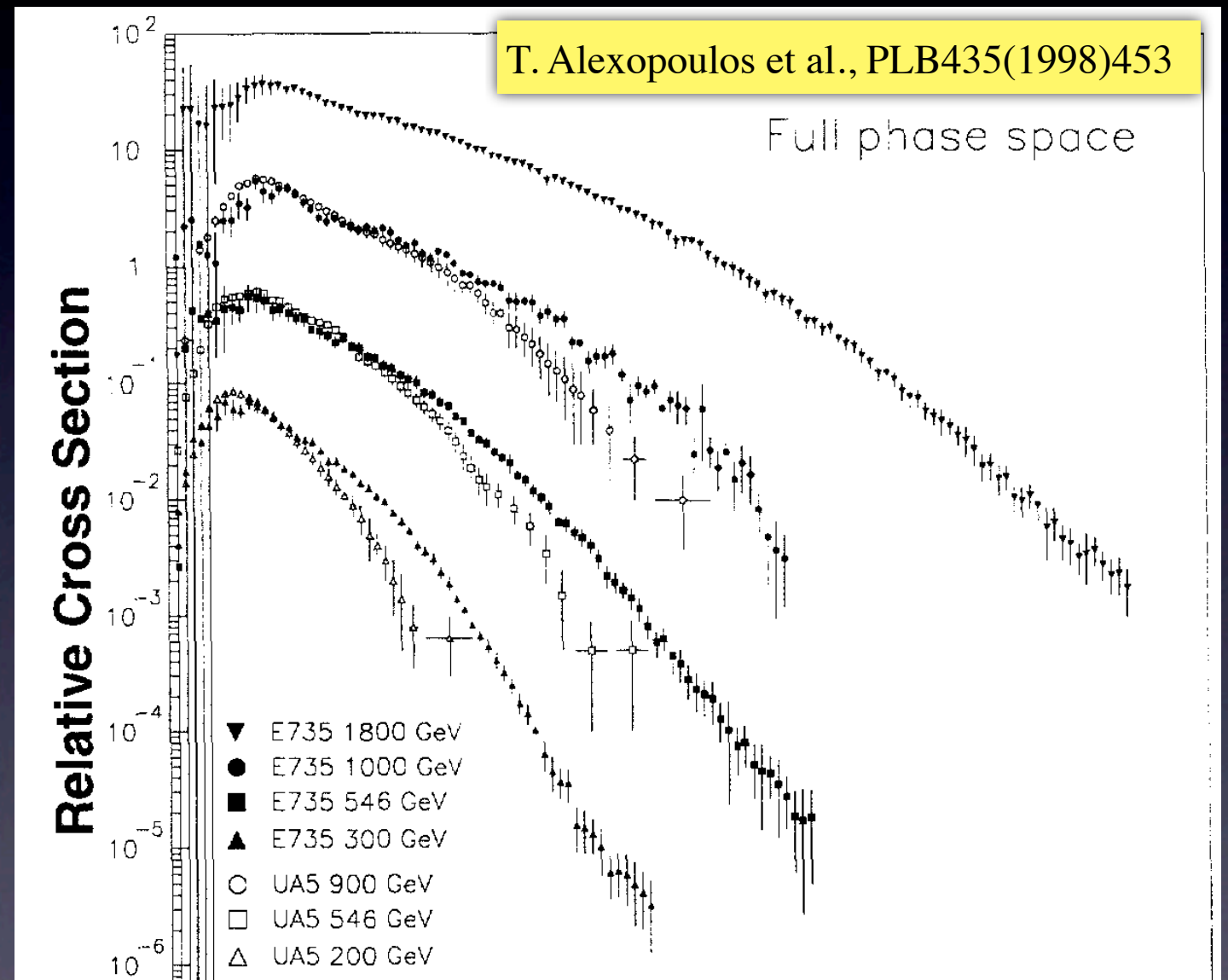
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Without even knowing how many tracks to tune to, how could we hope to constrain non-perturbative models (i.e., Monte Carlos) ?

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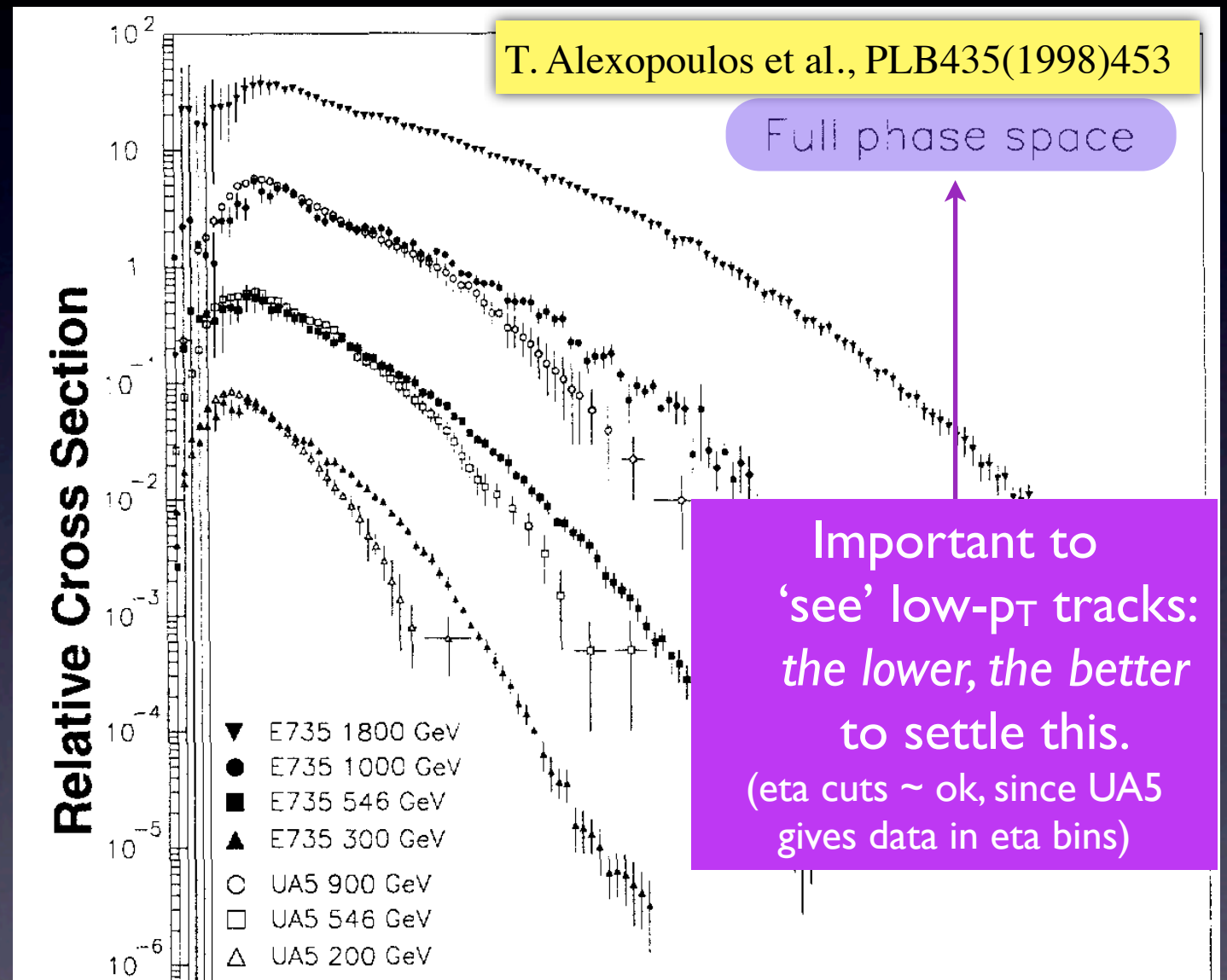


Again: LHC Measurements at 900 and 2360 GeV are  
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  - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)



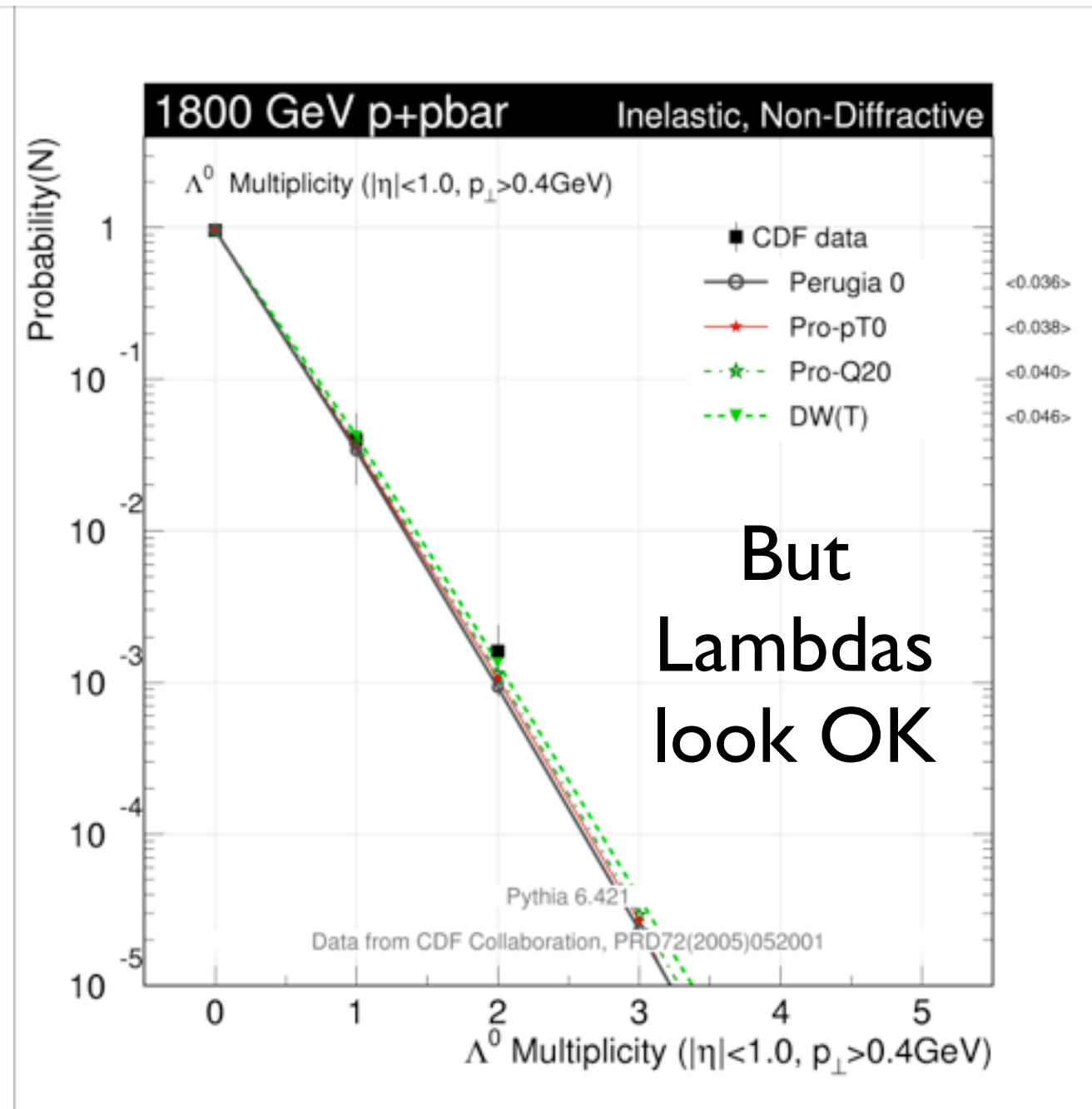
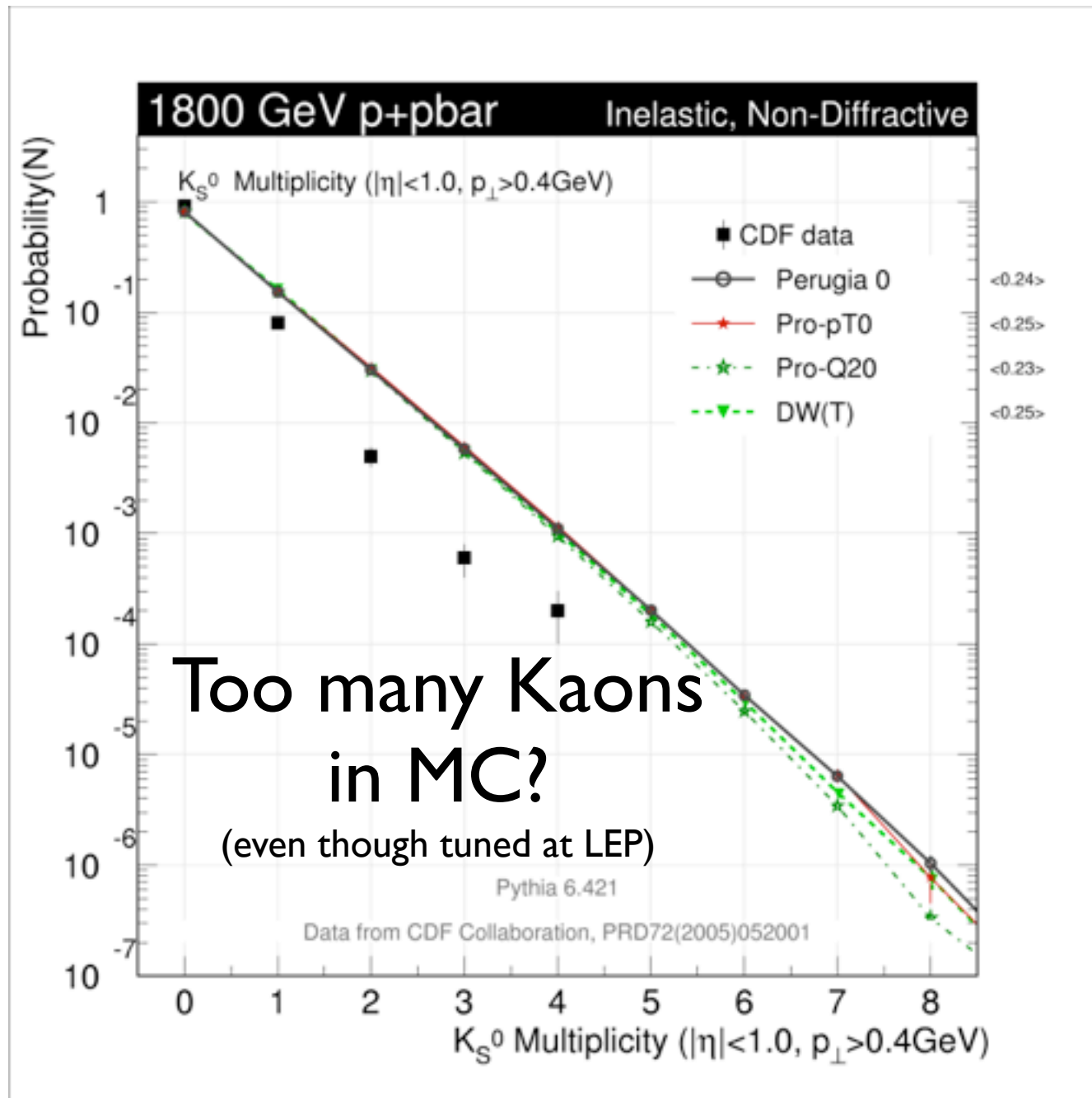
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- Check fragmentation *in situ* at hadron colliders
  - $N$  and  $p_T$  spectra (and  $x$  spectra normalized to 'jet'/minijet energy?)  
**Identified particles** highly important to dissect fragmentation

# The Kaon Problem

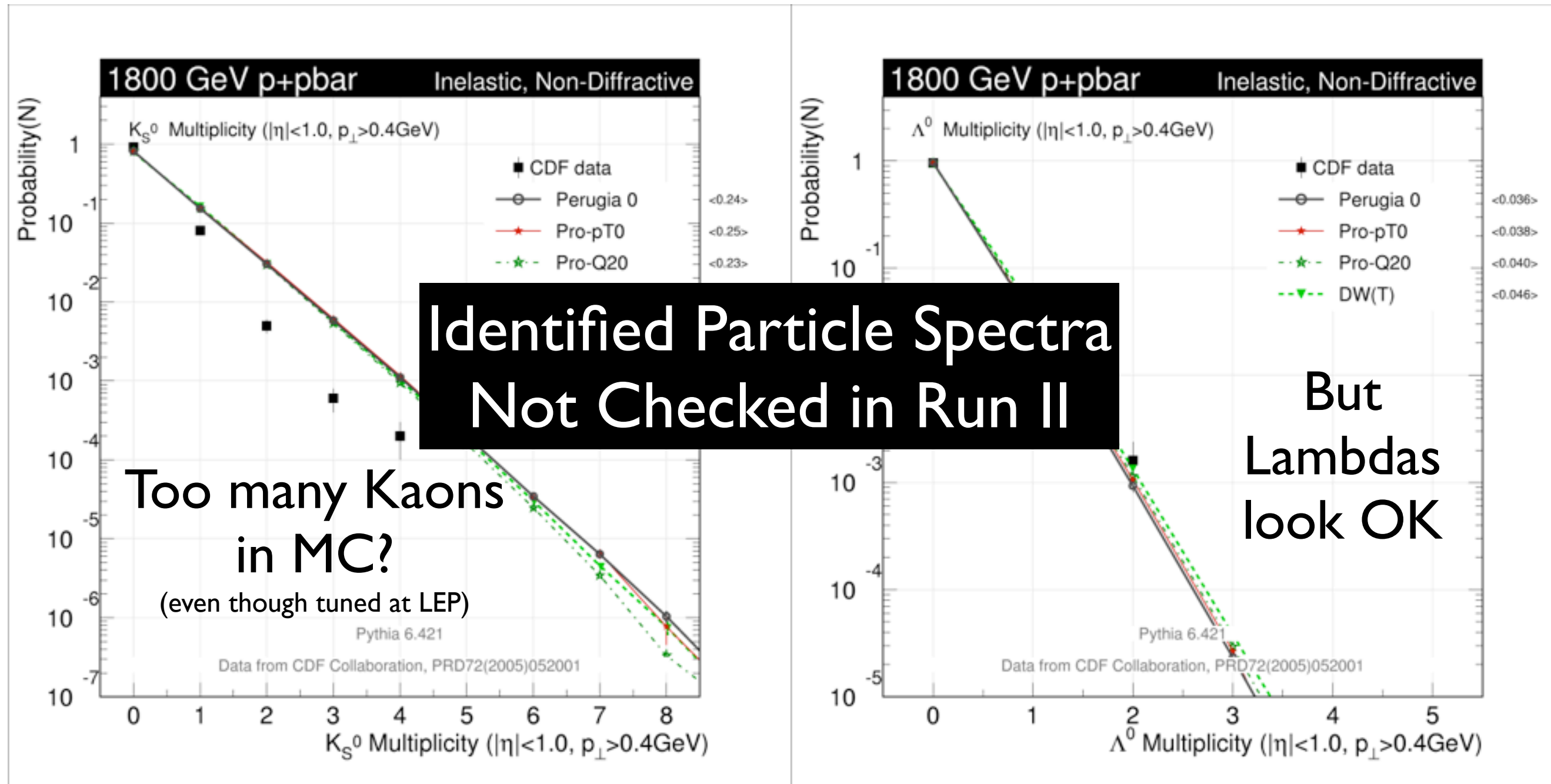


<http://home.fnal.gov/~skands/leshouches-plots>

PS, fermilab-conf-07-706-t, in arXiv:0803.0678 [hep-ph]



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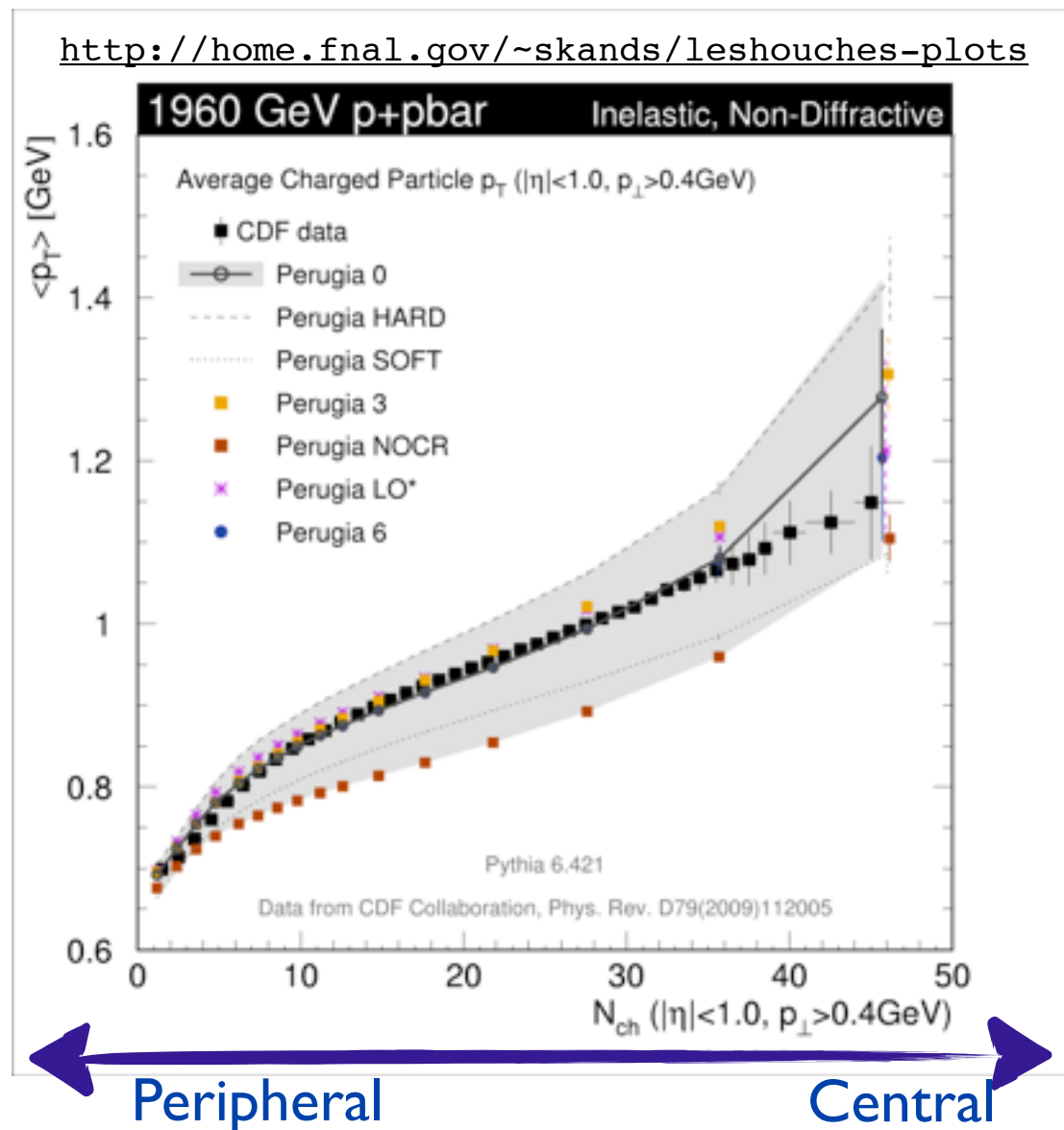
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**Identified particles** highly important to dissect fragmentation
  - (How) do the spectra change with (pseudo-)rapidity? (different dominating production/fragmentation mechanisms as fct of rapidity? E.g., compare LHCb with central?)
  - How do they change with event activity? (cf. heavy-ion ~ central vs peripheral collisions)

# Change with Event Activity

- One (important) example:  $\langle p_T \rangle(N_{ch})$



The  $p_T$  spectrum becomes harder as we increase  $N_{ch}$ .

Important tuning reference (highly non-trivial to describe correctly)

*(Color reconnections, string interactions, rescattering, collective flow in pp, ...?)*



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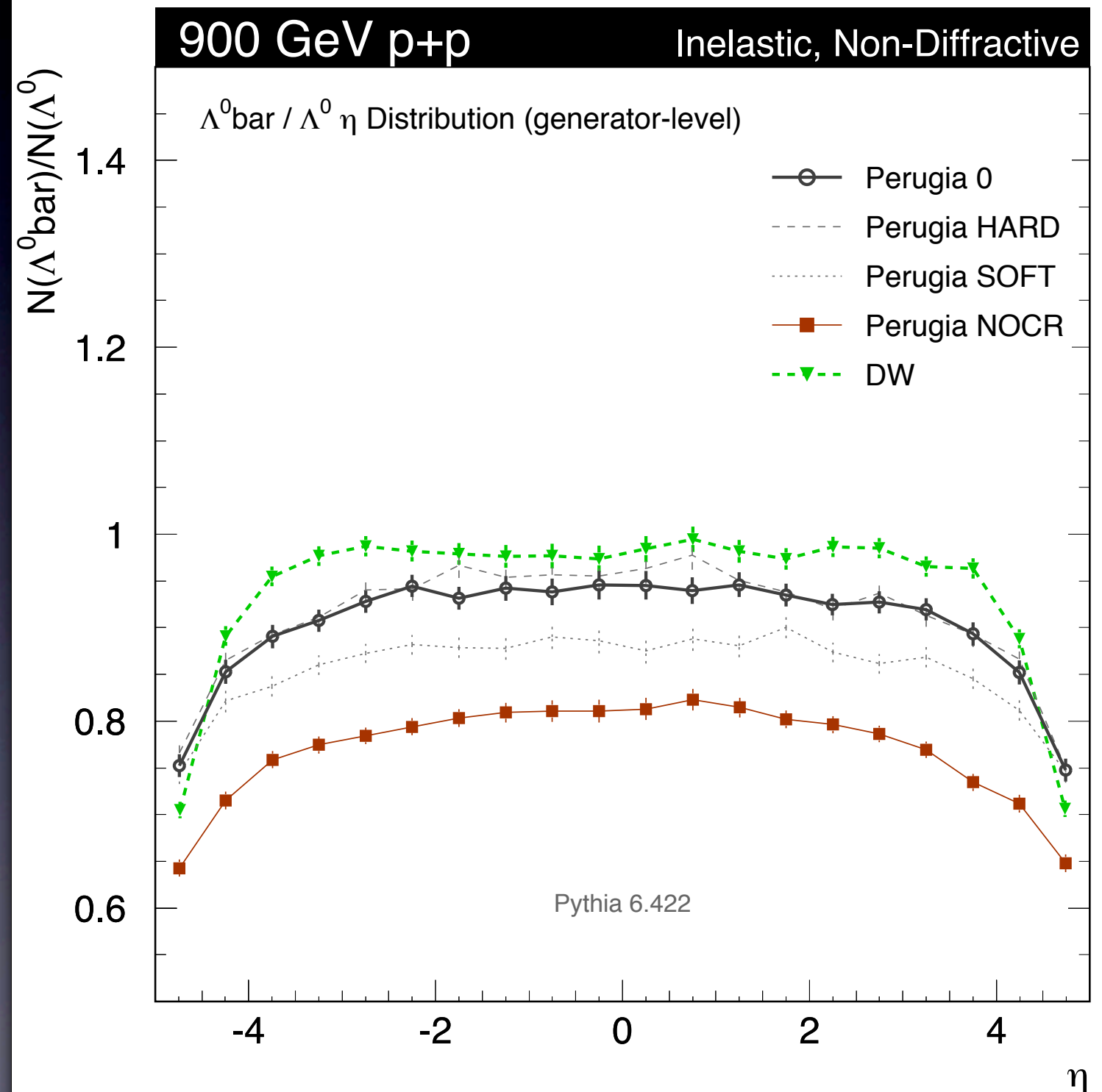
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  - Check extrapolation to forward region
    - Subir's synergy with Cosmic Ray Fragmentation
    - 'New' Physics: collective effects, multiple scatterings, low-x evolution, BFKL, ..., but central region remains important testing ground

# (Additional Observables)

- **Particle-Particle Correlations** probe fragmentation beyond single-particle level. E.g.,:
  - A baryon here, where's the closest antibaryon?
    - + Is the Baryon number of the beam carried into the detector?
  - A Kaon here, where's the closest strange particle?
    - + Multi-Strange particles. Over how big a distance is the strangeness 'neutralized'?
  - Charge correlations. Special case: is the charge of the beam carried into the detector?

# Baryon Transport

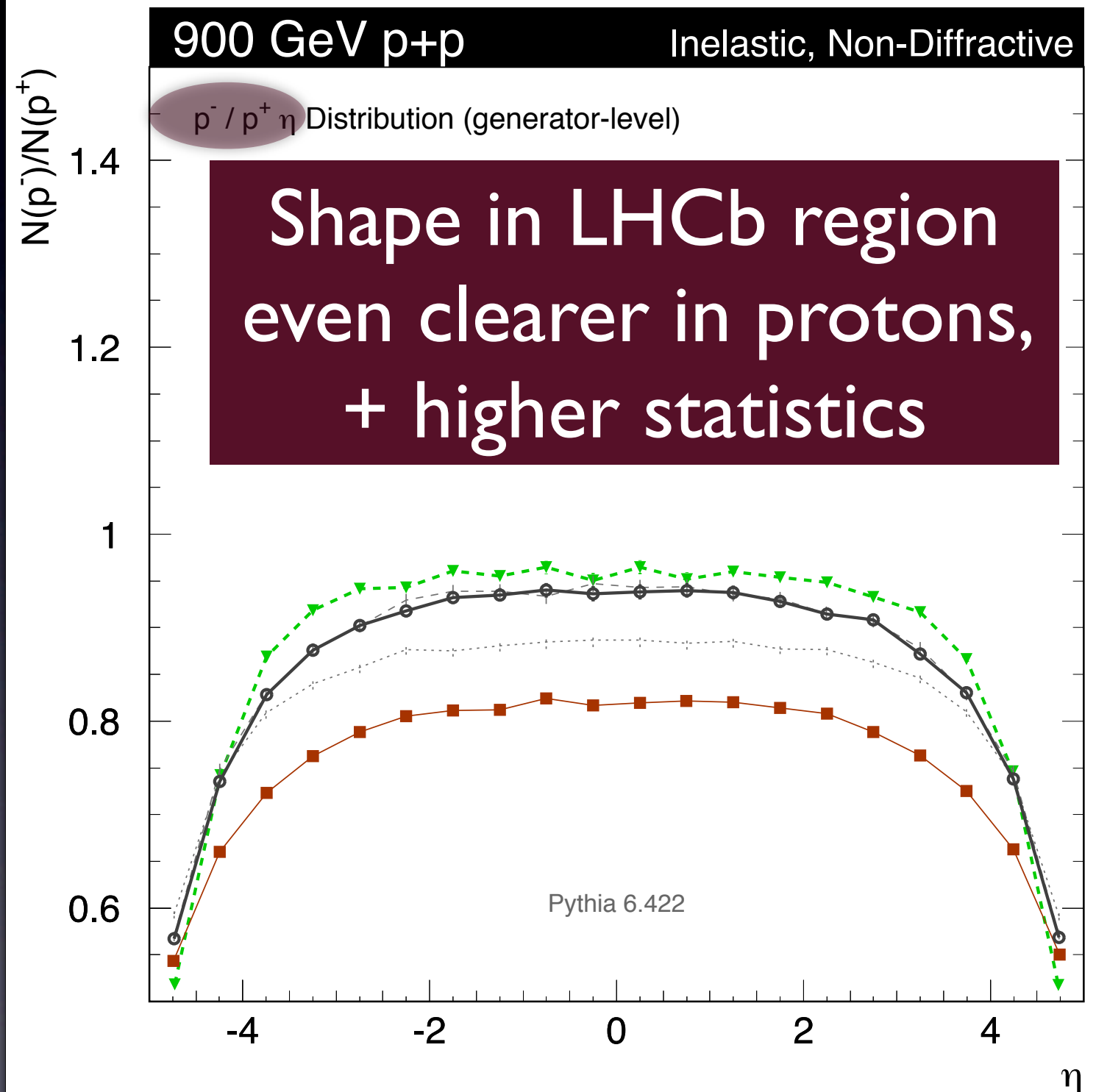
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- Don't listen to them
- (Still, can be used to gauge possible size of effect)





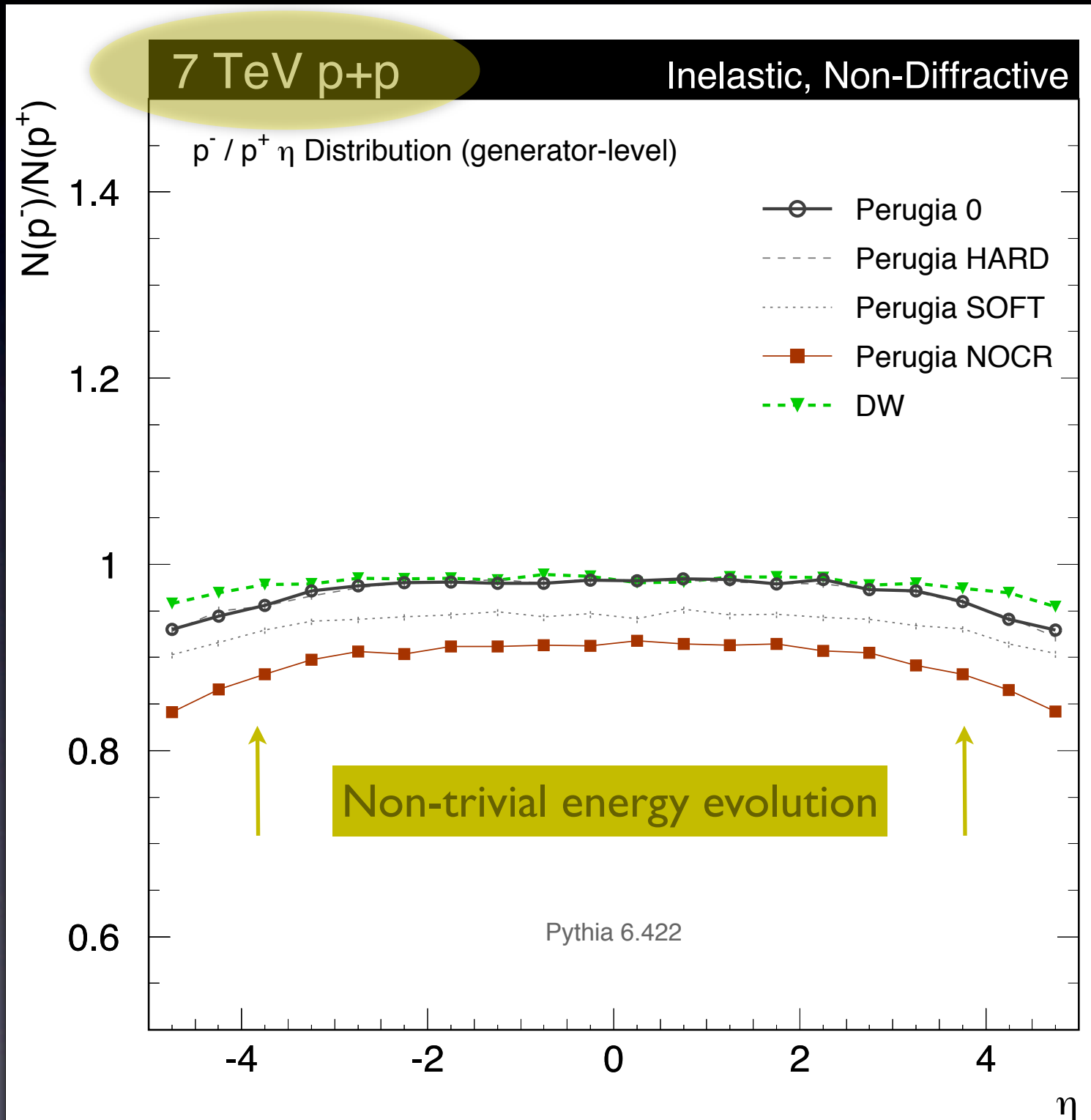
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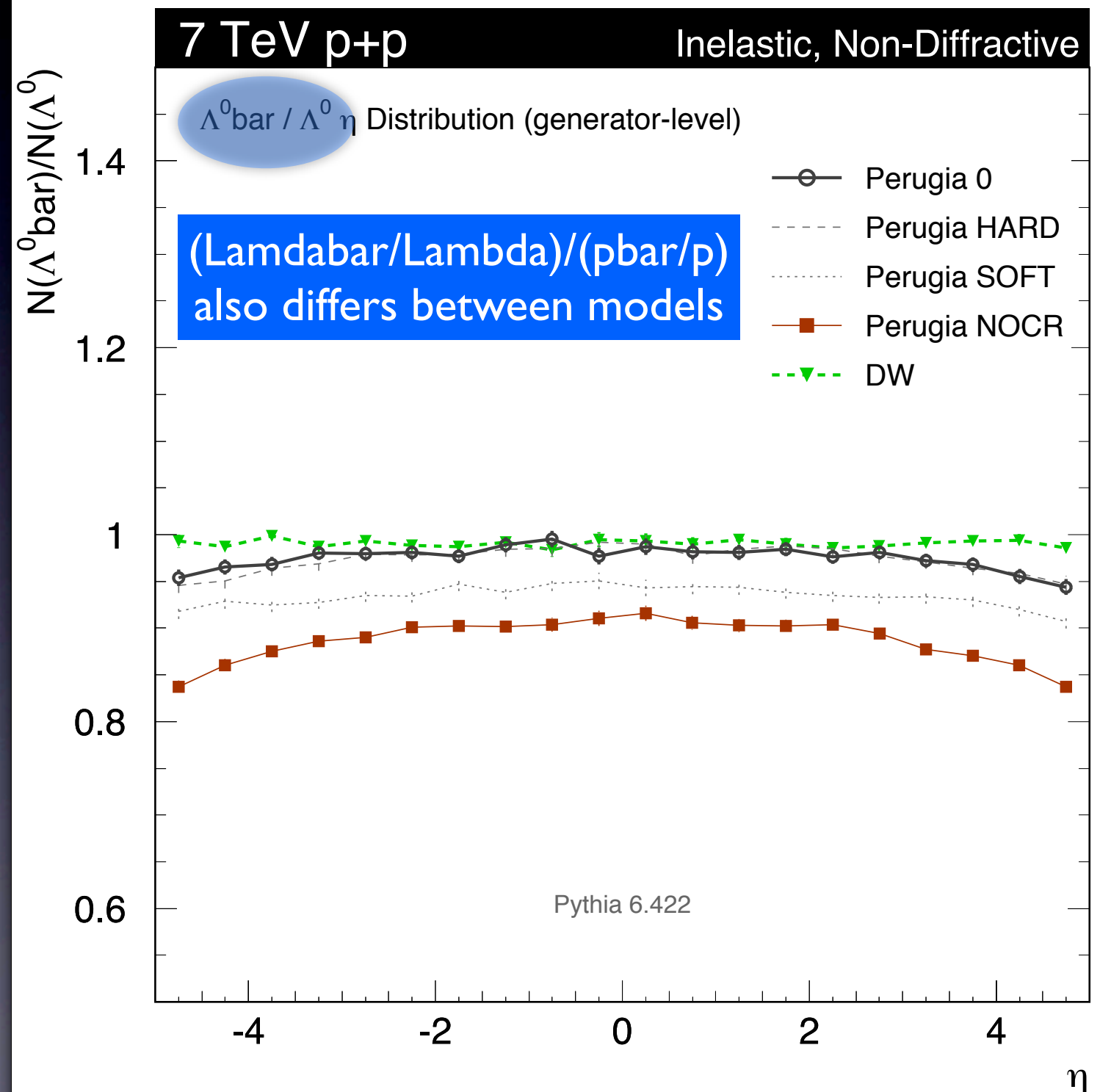
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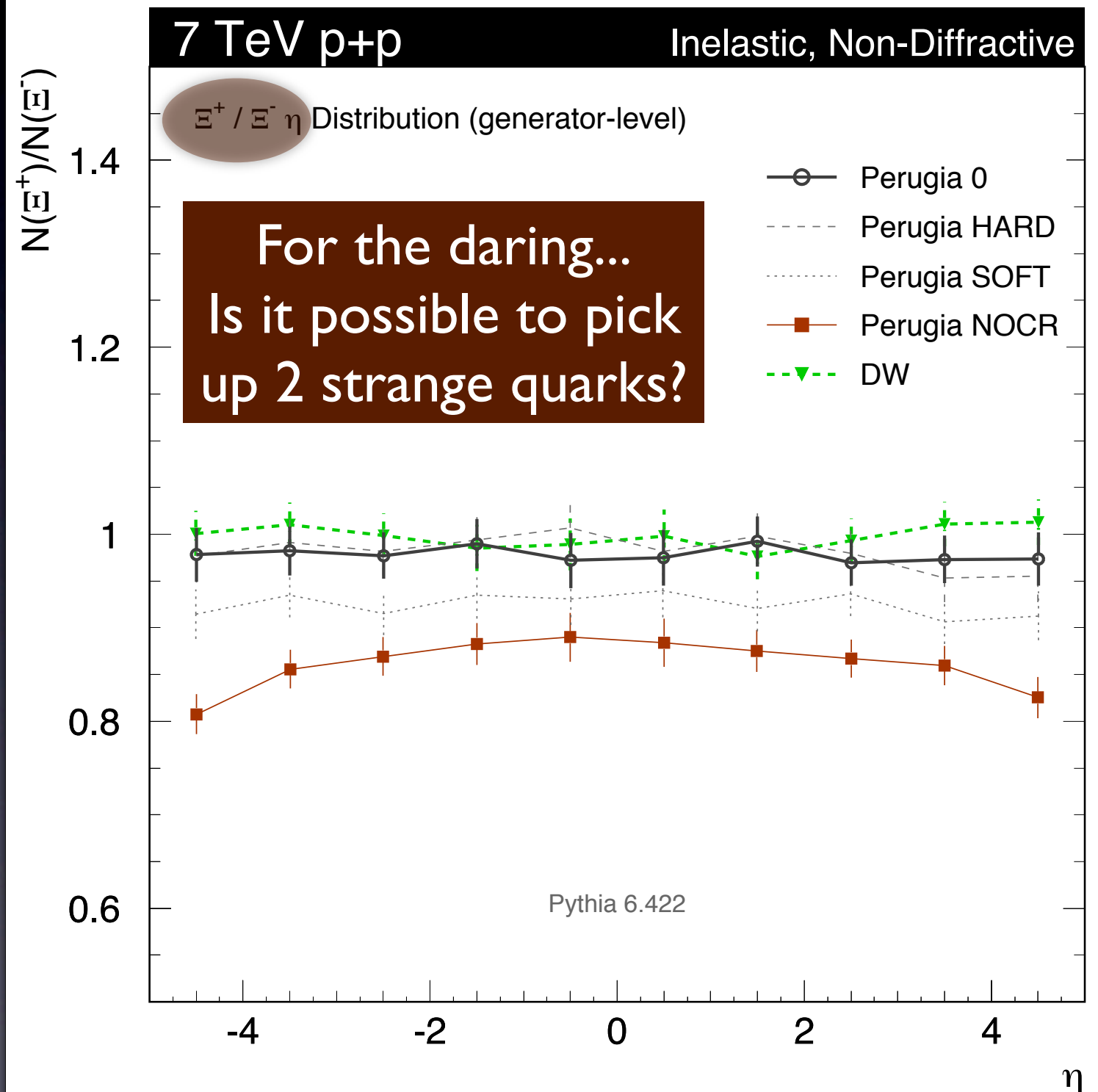
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# Summary

- The Low-Energy LHC runs offer a unique possibility to settle important business
- These are questions faced by every person (within or outside experiments) trying to constrain ('tune') physics models
- In a broader context, they concern our *knowledge of nature*

